

QCD CORRECTIONS TO $b\bar{b}/c\bar{c}$ PAIR PRODUCTION IN POLARIZED $\gamma\gamma$ COLLISIONS AND THE INTERMEDIATE MASS HIGGS SIGNAL¹

G. Jikia and A. Tkabladze

*Institute for High Energy Physics
142284, Protvino, Moscow region, Russia*

Abstract

We present production rates of the two- and three-jet final states for the processes of massive $c\bar{c}/b\bar{b}$ quark production in circularly polarized photon-photon collisions, including QCD radiative corrections. Lowest order cross section, one-loop virtual correction and gluon emission correction are shown to be of the same order of magnitude for $b\bar{b}$ quark production at $\sqrt{s_{\gamma\gamma}} \sim 100$ GeV. It is shown that the signal from intermediate mass Higgs boson is observable at photon-photon collider, although the statistical significance is substantially reduced with respect to the tree level calculation.

A very exciting potential application of photon-photon collisions at a 100-200 GeV linear collider is the intermediate mass Higgs boson production in photon fusion reaction [1–5]

$$\gamma\gamma \rightarrow H \rightarrow b\bar{b}.$$

In addition, new interesting method was proposed [6, 7] to measure the parity of the Higgs states in linearly polarized photon-photon collisions. It provides an opportunity to investigate non-trivial assignment of the quantum numbers for Higgs particles in extended models such as supersymmetric theories which include both scalar 0^{++} and pseudoscalar 0^{-+} states [8].

Extracting the intermediate mass Higgs signal in photon-photon collisions is a hard task since large number of $b\bar{b}/c\bar{c}$ background events must be rejected [1, 2, 9]. The crucial assumption is that these large backgrounds can be actively suppressed by exploiting the polarization dependence of the cross sections. Far above the threshold, the $\gamma\gamma \rightarrow q\bar{q}$ cross section is dominated by initial photons in the $J_z = \pm 2$ helicity state. Taking into account that the Higgs signal comes from the $J_z = 0$ channel, polarized collisions can be used to enhance the signal while simultaneously suppressing the background [1, 2] (see also detailed discussion in these proceedings [10, 11]). But

¹Based on invited talk given at the “Workshop on gamma-gamma colliders”, March 28-31, 1994, Lawrence Berkeley Laboratory

the question remains how do QCD radiative corrections influence these conclusions. While it is known that far above the threshold the magnitude of these corrections is moderate for unpolarized collisions [12, 13], one can expect that their effects will be especially large for $q\bar{q}$ production in $J_z = 0$ helicity state, where the tree level contribution is suppressed as m_q^2/s .

We present here the results of the one-loop calculation of the QCD corrections to $b\bar{b}/c\bar{c}$ quark pair production in polarized photon-photon collisions retaining the full dependence on the quark masses. The total cross section calculated up to the order $\alpha^2\alpha_s$ is given by the sum of tree-level $\gamma\gamma \rightarrow q\bar{q}$ contribution, the interference term between one-loop and the tree level contributions, and tree level contribution from quark pair production accompanied by gluon emission $\gamma\gamma \rightarrow q\bar{q}g$. The first two contributions lead to two parton final states converting mainly into two jets, while the third one leads to three parton production converting both into two- and three-jet final states. The reason is that three parton final states with collinear and/or soft gluon will appear experimentally as two jets. Moreover, only the sum of the cross sections of $q\bar{q}$ production and $q\bar{q}g$ with soft or collinear gluon is free from infrared divergences and has no singularities in the limit $m_q \rightarrow 0$. So, as usual, we consider the three parton state to represent two-jet final state if the invariant mass of two partons is sufficiently small

$$s_{i,j} < y_{cut}s_{\gamma\gamma},$$

where $s_{i,j} = (p_i + p_j)^2$ is the invariant mass squared of two partons i and j and $\sqrt{s_{\gamma\gamma}}$ is the total c.m.s. energy of two colliding photons.

Fig. 1 shows total (*i.e.* two-jet plus three-jet) and two-jet ($y_{cut} = 0.08$) cross sections for $b\bar{b}/c\bar{c}$ pair production in polarized monochromatic $\gamma\gamma$ collisions. While the QCD corrections for $J_z = \pm 2$ photon helicities are quite small, those for $J_z = 0$ enhance $c\bar{c}$ production by an order of magnitude or even larger. For $b\bar{b}$ production the situation is more complicated: the corrected total cross section is smaller than the tree level $\gamma\gamma \rightarrow b\bar{b}$ cross section for $\sqrt{s_{\gamma\gamma}} < 85$ GeV and larger for larger energies. The effect is more pronounced for two-jet production. For small values of $y_{cut} < 0.04$ the two-jet differential cross section is even negative in some regions of the phase space. This means that for $b\bar{b}$ production at $\sqrt{s_{\gamma\gamma}} \sim 100$ GeV all three contributions (lowest order, virtual and gluon emission) are of the same order of magnitude. This is unlike the case of $c\bar{c}$ production, where the gluon emission contribution dominates. Therefore the approach of [3, 11], where only one contribution from radiative processes $\gamma\gamma \rightarrow c\bar{c}g$, $b\bar{b}g$ is taken into account in the limit $m_c, m_b \rightarrow 0$ (for $J_z = 0$ and $m_q = 0$ the cross section is given by this only contribution), may be relevant for $c\bar{c}$ production, but is definitely not applicable for $b\bar{b}$ production.

Fig. 2 shows the events rates of signal and background two-jet final states in photon-photon collisions. We make here the same assumptions as in [2], *i.e.* we choose the broad photon-photon luminosity spectrum resulting from polarized linac and laser in the $\lambda_\gamma\lambda_e > 0$ direction, $\lambda_e = 0.9$, $\lambda_\gamma = 1$, parameter $x = 4.8$ and geometric factor $\rho = 0.6$ [2, 14]. We also assume the linac beam energy to be equal to 125 GeV

and integrated effective luminosity of 10 fb^{-1} . Such a choice is preferable when trying to cover the entire intermediate Higgs mass region. We ignore here backgrounds from $e\gamma \rightarrow eZ \rightarrow e b\bar{b}$ and $\gamma\gamma \rightarrow f\bar{f}Z$ processes [16], which are essential for $m_H \sim m_Z$. The backgrounds coming from the resolved photon contributions $\gamma g \rightarrow b\bar{b}$, $c\bar{c}$ are also shown. While resolved photon contributions make almost impossible to observe the intermediate mass Higgs signal at 500 GeV linear collider [9], these backgrounds are much less significant at 250 GeV due to a steeply falling gluon spectrum (see also [2, 7]). QCD corrections to Higgs decay into $b\bar{b}$ [15] are also taken into account. We use a cut of $|\cos\theta| < 0.7$ in the laboratory frame and not in c.m. frame as in [2]. Cut in the laboratory frame gives slightly better statistical significance of the Higgs signal. Finally, we assume 5% $c\bar{c}$ -to- $b\bar{b}$ misidentification probability. Thus, the combined background (*i.e.* $b\bar{b} + 0.05c\bar{c}$) is represented by dotted line and can be compared with the signal denoted by solid line.

Fig. 3 presents the statistical significance of the Higgs boson signal estimated from tree level as well as one-loop calculations including the resolved photon contributions. This plot assumes 90% $b\bar{b}$ -tagging efficiency for the $b\bar{b}$ final states and the resolution for reconstructing the invariant mass of a two-jet events to be Gaussian with $FWHM = 0.1m_H$. From this figure one can conclude that it is advantageous to select two-jet final states and to impose the angular cut in the laboratory frame. The account of QCD corrections reduces the statistical significance of Higgs signal almost by a factor of two in comparison to tree-level result. Nevertheless the intermediate mass Higgs boson can be observed in $\gamma\gamma$ collisions at least at the level of 5σ in the mass interval from 80 to 160 GeV. Our estimates here should be considered as a first-order determination of the influence of QCD radiative corrections on the statistical error in the measurement of the two-photon Higgs width. A more detailed analyses including full detector simulation is certainly needed.

We are grateful to D. Borden and O. Éboli for helpful discussions. Special thanks to organizers of the Workshop for financial help and to A. Sessler and M. Chanowitz for kind hospitality. The attendance at the Workshop was supported, in part, by the International Science Foundation travel grant.

References

- [1] J.F. Gunion and H.E. Haber, *Phys. Rev.* **D48** (1993) 5109.
- [2] D.L. Borden, D.A. Bauer, D.O. Caldwell *Phys. Rev.* **D48** (1993) 4018.
- [3] D. L. Borden, V. A. Khoze, W. J. Stirling, and J. Ohnemus, UCSB-HEP-94-05, DTP/94/12, UCD-94-8, hep-ph/9405401.

- [4] P.M. Zerwas, Proceedings of the VIII Int. Workshop on Photon–Photon Collisions, Shores (Jerusalem Hills) 1988.
- [5] S. Brodsky, in Physics and Experiments with Linear e^+e^- Colliders, Waikoloa, Hawaii, 1993, Ed. F.A. Harris *et al.*, World Scientific, vol. I, p. 295; J.F. Gunion, *ibid.* p. 166.
- [6] B. Grzadkowski and J.F. Gunion, *Phys. Lett.* **B294** (1992) 361.
- [7] M. Kramer, J. Kühn, M.L. Stong, and P.M. Zerwas, preprint DESY 93–174, December 1993, hep-ph/9404280.
- [8] J.F. Gunion and H.E. Haber, *Nucl. Phys.* **B272** (1986) 1; *Nucl. Phys.* **B278** (1986) 449.
- [9] O.J.P. Éboli, M.C. Gonzalez-Garcia, F. Halzen, and D. Zeppenfeld, *Phys. Rev.* **D48** (1993) 1430.
- [10] O.J.P. Éboli, these proceedings.
- [11] D.L. Borden, these proceedings.
- [12] J.H. Kühn, E. Mirkes, J. Steegborn, *Z. Phys.* **C57** (1993) 615.
- [13] M. Drees, M. Krämer, J. Zunft and P.M. Zerwas, *Phys. Lett.* **B306** (1993) 371.
- [14] V.I. Telnov, these proceedings.
- [15] E. Braaten and J.P. Leveille, *Phys. Rev.* **D22** (1980) 715; M. Drees and K.-I. Hikasa, *Phys. Lett.* **B240** (1990) 455, *Phys. Rev.* **D41** (1990) 1547.
- [16] I.F. Ginzburg and V.G. Serbo, in Physics and Experiments with Linear e^+e^- Colliders, Waikoloa, Hawaii, 1993, Ed. F.A. Harris *et al.*, World Scientific, vol. II, p. 563.

Figure captions

Fig. 1. Cross sections for $\gamma\gamma \rightarrow c\bar{c}$ and $\gamma\gamma \rightarrow b\bar{b}$ for polarized monochromatic photon beams, $++$, $+-$ correspond to $J_z = 0$ and $J_z = \pm 2$, respectively. Solid (dashed) line is tree level (one-loop corrected) cross section for $b\bar{b}$ production. Dotted (dash-dotted) line is tree level (one-loop corrected) cross section for $c\bar{c}$ production. First figure gives total cross section. The second is two-jet production cross section.

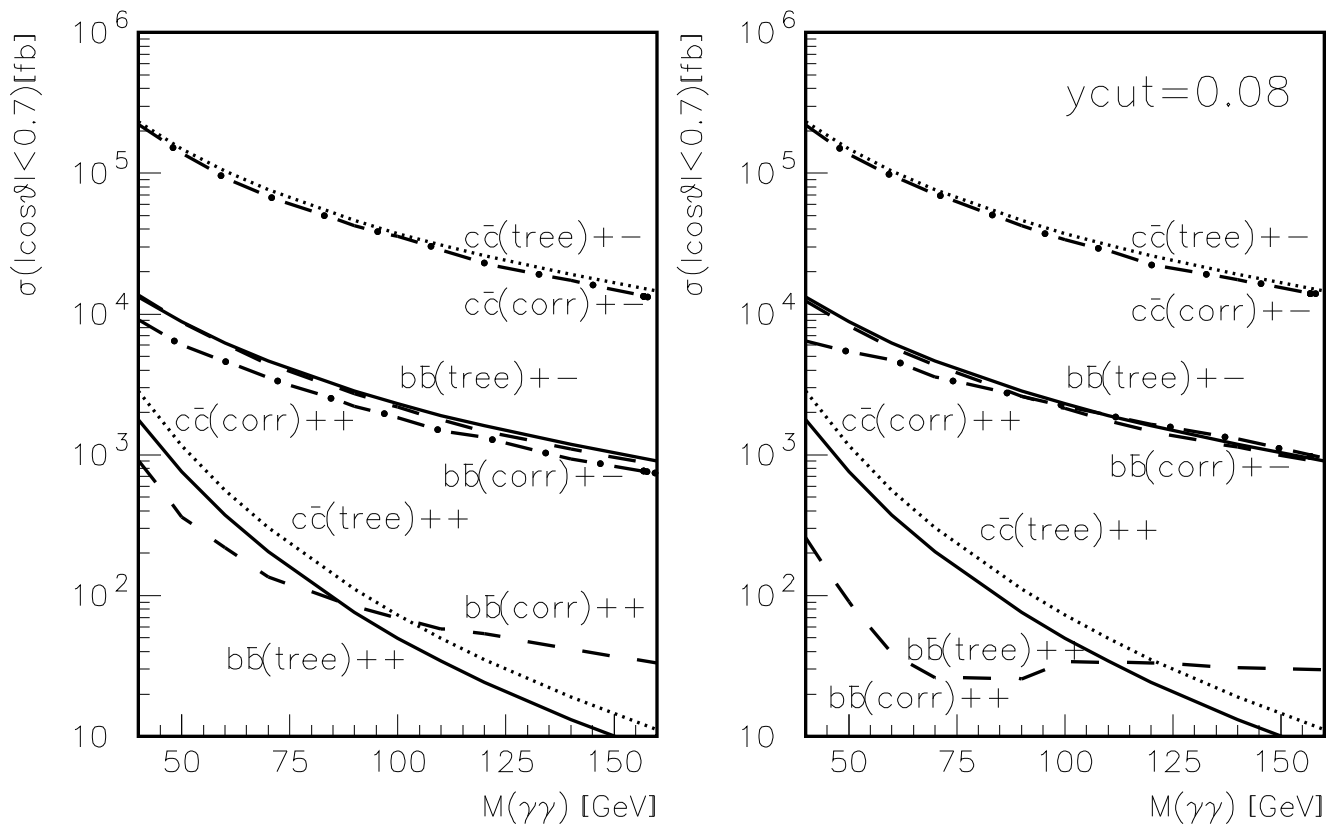
Fig. 2. Expected event rates for the Higgs signal and background processes. Two-jet final states are considered. Lowest order as well as one-loop corrected results are shown.

Fig. 3. Statistical significance of the intermediate mass Higgs boson signal. Solid line corresponds to two-jet final states with the angular cut in the laboratory frame. Dashed curves correspond to cut in c.m.s. of colliding photons. “All” represents the sum of two- and three-jet final states. Dash-dotted curves represent the results of the lowest order calculation and the effect of the account of resolved photon contribution.

This figure "fig1-1.png" is available in "png" format from:

<http://arXiv.org/ps/hep-ph/9406428v1>

Figure 1. G. Jikia and A. Tkabladze



This figure "fig1-2.png" is available in "png" format from:

<http://arXiv.org/ps/hep-ph/9406428v1>

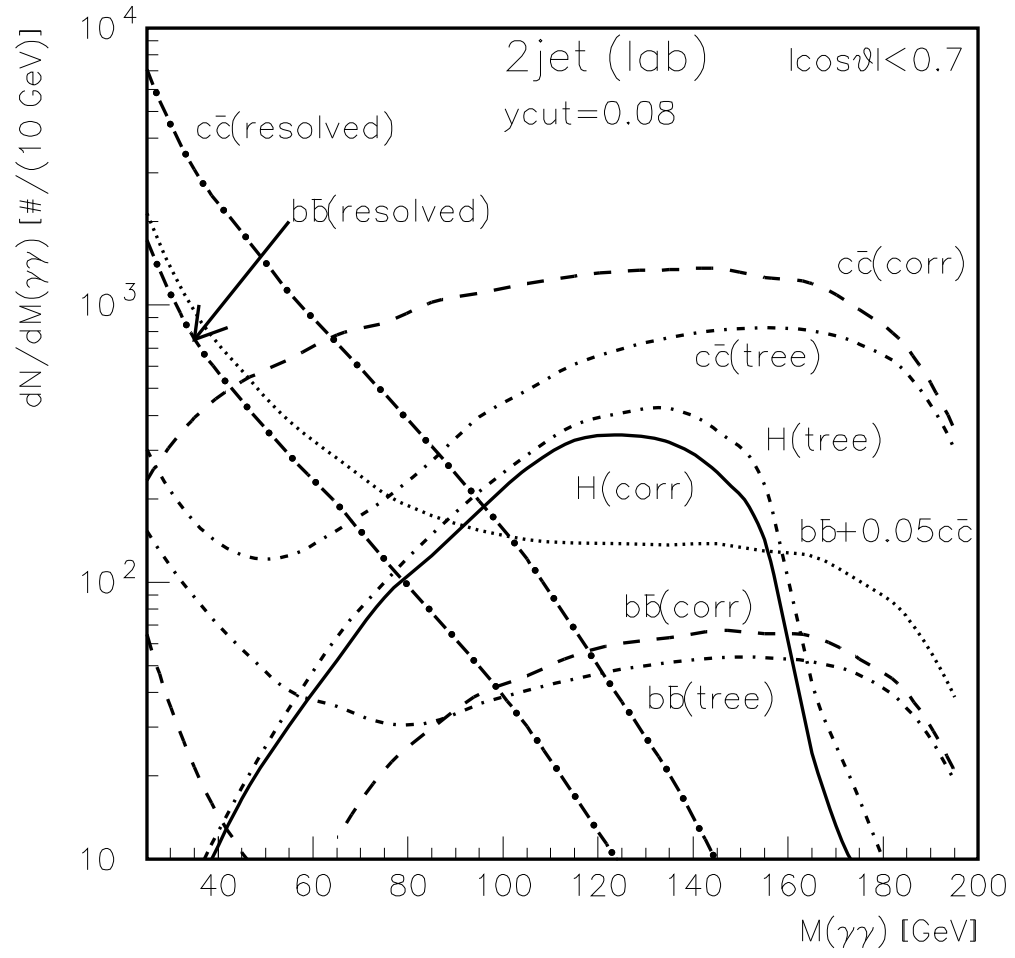


Figure 2. G. Jikia and A. Tkabladze

This figure "fig1-3.png" is available in "png" format from:

<http://arXiv.org/ps/hep-ph/9406428v1>

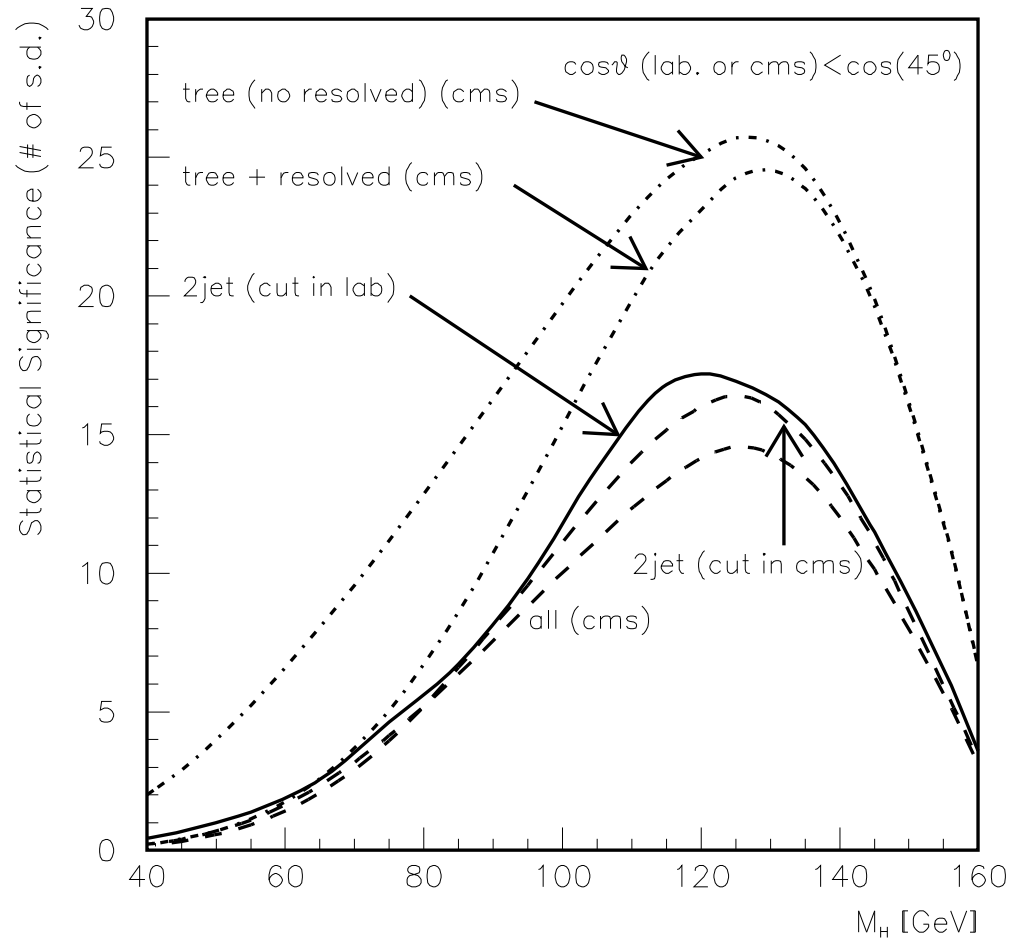


Figure 3. G. Jikia and A. Tkabladze